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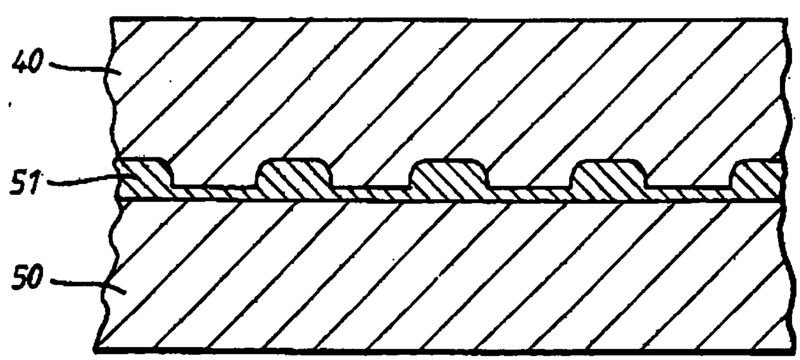
(54) Title: MANUFACTURE OF GRATING STRUCTURES



(57) Abstract

An embossing tool (40) is constructed with the patterning appropriate f r the constructi n of the optical grating structure of a DFB laser. This tool is advanced into the surface of a UV-curable resin layer (51) applied to the surface of a semiconductor slice (50), and the resulting embossed portion of the resin layer (51) is thinned to create ridges (80) separated by intervening windows to form a mask for etching of the channels (81) of a DFB grating structure in the surface of the underlying semiconductor slice.

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MANUFACTURE OF GRATING STRUCTURES

This invention relates to the making of grating structures in the surfaces of bodies, particularly, but not necessarily exclusively, the making of optical grating structures in semiconductor bodies such as for instance is called for in the manufacture of distributed feedback (DFB) lasers and distributed Bragg reflector (DBR) lasers.

A first order grating for an InGaAsP DFB laser operating at a wavelength of 1330 nm typically has a pitch of about 195 nm, while that of one operating at a wavelength of 1550 nm typically has a pitch of about 230 nm. Additional constraints are clearly required if the system is to be capable of creating phase-shifted gratings.

Currently DFB lasers are being produced commercially whose gratings have been produced using e-beam lithography, or using photolithography. In the case of photolithography, a number of different interferometric techniques have been devised for achieving the requisite resolution in the face of difficulties presented by the resolution limit set by classical diffraction theory. A principal problem with e-beam lithography is that the process is essentially a serial one in which each line of each DFB laser has to be separately written. (Typically a period of several hours may be required to write a single two-inch wafer).

The present invention is directed to a method of grating structure manufacture which does not necessitate the use of interferometric techniques and thus can avoid the limitations imposed by such use, and which allows repeated use of a tool thereby aff rding the possibility of a considerable reduction in processing time when engaged in mass production.

According to the present invention there is provided a method of providing a grating structure in a surface of a body, which method includes the steps of:-

providing a relief structure embossing tool, applying a layer of a curable material to said surface of the body,

advancing said embossing tool into said layer to generate therein a complementary relief pattern,

curing the relief patterned layer,

eroding the cured relief patterned layer to expose portions of the underlying body in regions thereof registering with the thinner portions of the cured relief patterned layer and leaving residual other portions of the cured relief patterned layer, and

etching said exposed portions of the underlying body, using said residual other portions of the layer as mask material for said etching.

The present invention may be applied to a semiconductor manufacturing process that involves forming an embossed optical grating in a layer of resin resist deposited upon a semiconductor substrate, processing this resist layer to convert its embossed pattern into an apertured pattern which is then used as a mask for etching a corresponding pattern into the surface of the underlying semiconductor substrate.

The invention also provides a method of making a DFB or DBR semiconductor laser in which a DFB or DBR optical grating structure is formed in a surface of a semiconductor body by etching using an etch mask patterned by embossing.

The embossing tool can for instance be made by an e-beam lithographic process similar to that used for e-beam lithography of a grating direct upon a semiconductor wafer. Alternatively it could be made by one of the other lithographic techniques currently used for DFB laser manufacture. The manufacture of the embossing tool by e-beam lithography is liable to take as much time as the writing of the same lines on an equivalent area of semiconductor slice, and so there is no saving of tim here. An overall saving of time comes from the fact that the embossing time is short compared with the line writing

time, and the same embossing tool can be used many times over. Furthermore, the embossing does not need to be performed in vacuo, thus avoiding the tedious loading time and effort associated with e-beam writing of semiconductor slices which, of course, does necessarily require a vacuum.

There follows a description of the making of an embossing tool and of its use in creating, in a manner embodying the invention in a preferred form, an optical grating structure in the surface of a semiconductor slice. The description refers to the accompanying drawings, in which:-

Figures 1 to 4 schematically depict successive stages in the manufacture of an embossing tool, and

Figures 5 to 8 schematically depict successive stages in the making of an optical grating structure surface on a semiconductor body with the aid of that tool.

Referring to Figure 1, a low expansion UV transmissive optical flat 10, for instance of fused quartz, is provided with a mask layer 11, for instance of chromium, and then a layer of e-beam resist 12. An electron beam machine (not shown) is then used to write an optical grating structure into the resist layer 12. The layer is then processed using conventional lithographic techniques to develop the lines and produce a structure as depicted in Figure 2 in which windows are opened between adjacent stripes 12a of residual e-beam resist. These stripes 12a are employed as a mask for wet or dry etching the underlying chromium layer 11. The resulting residual stripes 11a (Figure 3) of chromium are, in their turn, employed as a mask for reactive ion etching of the underlying silica, using for instance carbon tetrafluoride as the etchant. Finally the residual chromium stripes 11a are removed by etching to leave the completed embossing tool 40 as depicted in Figure 4.

Referring now to Figure 5, a semiconductor slice 50 is provided with a resin layer 51 which is to be embossed with the embossing tool 40 of Figure 4. The semiconductor slice has an InP substrate upon which have been grown a number of InGaAsP layers (not shown) by vapour phase epitaxy as the first stage of a 2-stage epitaxial growth process employed in the manufacture of DFB lasers.

Embossing techniques in which relatively fin detail is embossed into a resin layer are already known for instanc from th manufacture of compact discs. In conventional compact disc manufacture such resins are heat-cured but, whereas the shrinkage that accompanies this curing can be tolerated because it does not lead to any significant degradation of the digitally stored information content of the compact disc, such shrinkage is much to great to be acceptable for DFB or DBR grating manufacture for which the absolute value of the grating pitch is critical, as also is the preservation of the integrity of any phase-shift region. However it is found that these finer resolution requirements can be met by certain UV-curing resins. Thus for instance M. Okai et al describe the making of a UV-cured resin-embossed grating for use in DFB laser manufacture in an article entitled 'Novel method to fabricate corrugation for a λ/4-shifted distributed feedback laser using a grating photomask', Applied Physics Letters, Volume 55, Number 5 pages 415-7, 31st July 1989. In that instance the embossed resin layer is not a layer applied to the semiconductor surface for subsequent use as mask for etching the underlying semiconductive material, but instead is applied to a transparent substrate to form a phase object through which coherent light is projected to produce an interference pattern that is employed to pattern a layer of photoresist applied to the semiconductor surface.

A suitable UV-curing resin, with appropriate release properties and dimensional stability for use as the layer 51 of Figure 5 is a resin supplied by E.I. du Pont de Nemours & Company. A preferred class of resin for this purpose is the class of UV-curing resin in which differential partial UV-induced polymerisation causes a depression of a monomer content of the resin which, in its turn, induces a diffusion of monomer from the initially less-exposed (or initially unexposed) regions into the initially more exposed regions, thereby creating an enhanced molecular concentration in these regions that were initially more exposed. Such a monomer may for instance be N-vinyl carbazole. A feature of such a resin is that its photo-induced monomer flow provides a way of achieving, at relatively low embossing pressures, relatively high quality reproduction in the resin of relatively highly re-entrant and high resolution profile features of the embossing surface of the embossing tool. This is particularly useful when attempting to emboss a resin layer supported upon a relatively brittle substrate, such as one

substrate, such as one made of single crystal indium phosphide. Using this type of resin, there can in some circumstances be advantage in using an embossing tool designed to entrance the photo-induced monomer flow by augmenting the differential UV exposure between those portions of the resin registering with troughs in the embossing tool and these portions registering with protrusions. This augmenting may be achieved by providing the tool surface of the embossing tool with an optically absorbing or optically reflective surface layer (not shown) in some regions but not others so as to form a pattern conforming to the relief pattern of the tool.

The embossing tool 40 of Figure 4 is advanced into the uncured resin layer 51, as depicted in Figure 6. Ultra-violet light is then directed through the embossing tool 40 and into the resin layer to cure it before removing the tool to leave exposed the resin layer 51 in its embossed form as depicted in Figure 7. The embossing tool may now be moved to another location (not shown) to emboss another part of the resin layer under which there is to be formed the grating structure of a second DFB laser, and this location is also irradiated with ultra-violet light through the embossing tool to produce localised curing of the underlying resin. Before proceeding to the next stage of manufacture, comprising the thinning of the now-embossed resin layer 51, for instance by ion etching, this embossing and localised curing procedure may be repeated to produce as many localised embossed regions as are required to be formed in the semiconductor slice. In the foregoing description it has been implicitly assumed that the embossing tool has been constructed to be large enough to provide the grating structure for only a single laser at a time, but it will be apparent that the tool can be made larger so as to emboss the grating structures of a single compact group of lasers at a time.

In the course of the thinning of the layer 51, the thicker parts 71 (Figure 7) of the layer that registered with recesses in the embossing tool 40 become reduced in thickness, but remain intact, whereas the thinner parts 72 that registered with protrusions of the embossing tool become eroded entirely away. In this way the integrity of the layer 51 is lost in the embossed regions, and in its place there is formed a set of stripes 80 (Figure 8) which are utilised as a mask for the etching of the underlying semiconductor slice 50, for instance by reactive ion etching

or by wet etching, to form the grooves 81 of a DFB grating structure. Th r mains of the resin layer 51 are then entirely r moved preparatory for the second stage of epitaxial growth, and further processing of the slice 50 before it is divided up into individual laser chips (not shown).

CLAIMS

1. A method of providing a grating structure in a surface of a body, which method includes the steps of:-

providing a relief structure embossing tool, applying a layer of a curable material to said surface of the body,

advancing said embossing tool into said layer to generate therein a complementary relief pattern,

curing the relief patterned layer,

eroding the cured relief patterned layer to expose portions of the underlying body in regions thereof registering with the thinner portions of the cured relief patterned layer and leaving residual other portions of the cured relief patterned layer, and

etching said exposed portions of the underlying body, using said residual other portions of the layer as mask material for said etching.

2. A method as claimed in claim 1, wherein the relief patterned resin layer is cured with ultra-violet light directed into the layer through the embossing tool.

3. A method as claimed in claim 1 or 2, wherein said body is a semiconductor body.

4. A method of providing an optical grating structure in a surface of a body, which method is substantially as hereinbefore described with reference to the accompanying drawings.

5. A semiconductor device having a distributed feedback or a distributed reflector by an optical grating structure provided by the method claimed in claim 3 or 4.

6. A method of making a DFB or DBR semiconductor laser in which a DFB or DBR optical grating structure is formed in a surface of a semiconductor body by etching using an etch mask patterned by embossing.

AMENDED CLAIMS

[received by the International Bureau on 24 August 1993 (24.08.93); new claim 3 added; claims 3-5 renumbered as claims 4-7 other claims unchanged (2 pages)]

1. A method of providing a grating structure in a surface of a body, which method includes the steps of:-

providing a relief structure embossing tool, applying a layer of a curable material to said surface of the body,

advancing said embossing tool into said layer to generate therein a complementary relief pattern,

curing the relief patterned layer,

eroding the cured relief patterned layer to expose portions of the underlying body in regions thereof registering with the thinner portions of the cured relief patterned layer and leaving residual other portions of the cured relief patterned layer, and

etching said exposed portions of the underlying body, using said residual other portions of the layer as mask material for said etching.

2. A method as claimed in claim 1, wherein the relief patterned resin layer is cured with ultra-violet light directed into the layer through the embossing tool.

3. A method as claimed in claim 2 wherein the surface of the embossing tool that generates the complementary relief pattern in the layer of curable material is provided with an optically absorbing or optically reflective surface layer in selected regions so as to form a pattern conforming to the relief pattern.

4. A method as claimed in claim 1, 2, or 3, wherein said body is a semiconductor body.

5. A method of providing an optical grating structure in a surface of a body, which method is substantially as hereinbefore described with reference to the accompanying drawings.

6. A semiconductor device having a distributed feedback or a distributed reflector by an optical grating structure provided by the method claimed in claim 3, 4 or 5.

7. A method of making a DFB or DBR semiconductor laser in which a DFB or DBR optical grating structur is formed in a surface of a semiconductor body by etching using an etch mask patterned by embossing.

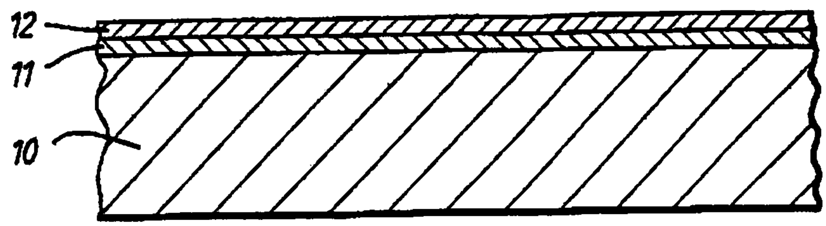

Fig. 1.

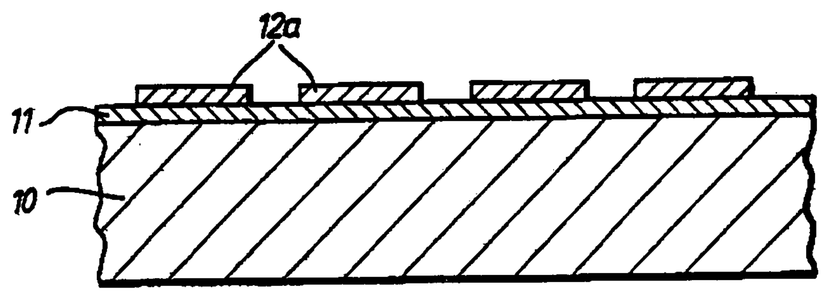

Fig. 2.

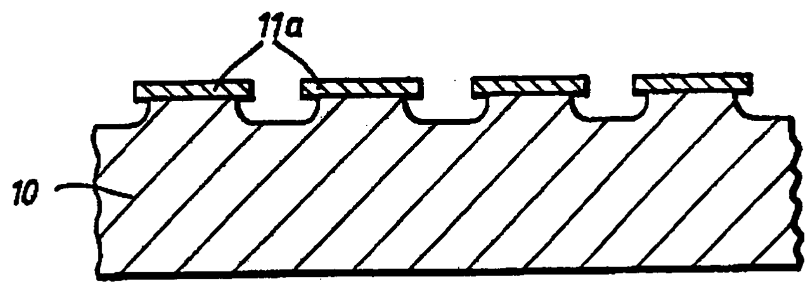

Fig. 3.

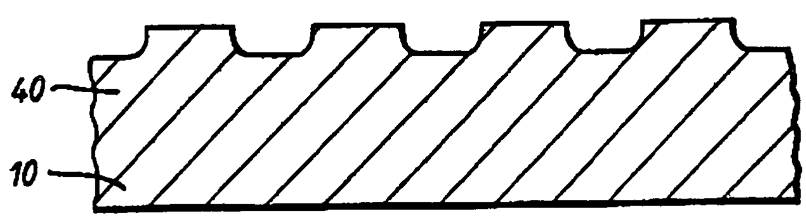

Fig. 4.

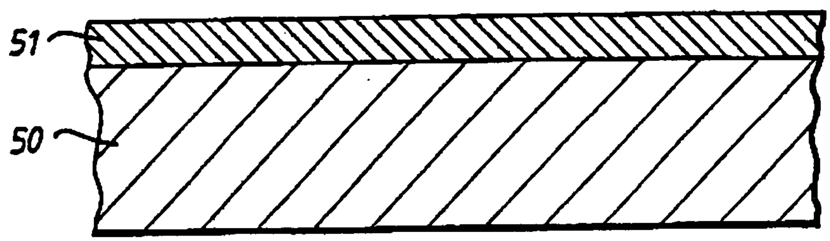

Fig.5.

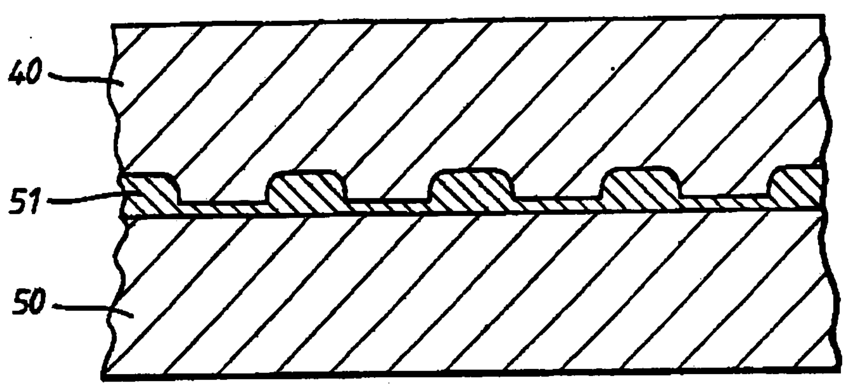

Fig.6.

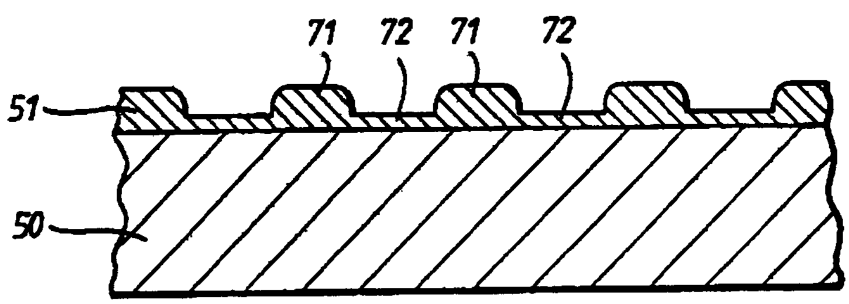

Fig. 7.

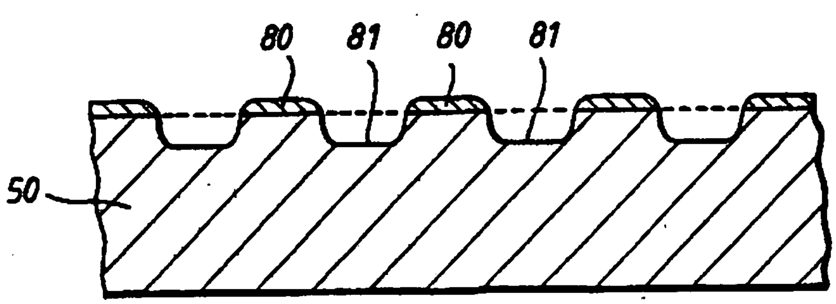

Fig.8.

INTERNATIONAL SEARCH REPORT

International Application No PCT/GB 93/00750

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all)[6]

According to International Patent Classification (IPC) or to both National Classification and IPC

Int.Cl. 5 H01S3/085; G02B5/18

II. FIELDS SEARCHED

Minimum Documentation Searched[7]

Classification System	Classification Symbols
Int.Cl. 5	H01S ; G02B

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched[8]

III. DOCUMENTS CONSIDERED TO BE RELEVANT[9]

Category[o]	Citation of Document,[11] with indication, where appropriate, of the relevant passages[12]	Relevant to Claim No.[13]
A	EP,A,0 175 460 (JOHANNES HEIDENHAIN GMBH) 26 March 1986 see the whole document ---	1-6
A	JOURNAL OF VACUUM SCIENCE AND TECHNOLOGY: PART B vol. 10, no. 1, February 1992, NEW YORK US pages 114 - 117 K-H SCHLERETH 'Embossed grating lead chalcogenide distributed feedback lasers' see the whole document ---	1,6
A	US,A,4 810 547 (MINAMI) 7 March 1989 see the whole document ---	1,6
	-/--	

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IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
08 JULY 1993	14 JUIL 1993
International Searching Authority	**Signature of Authorized Officer**
EUR PEAN PATENT OFFICE	CLAESSEN L.M.

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III. DOCUMENTS CONSIDERED TO BE RELEVANT (CONTINUED FROM THE SECOND SHEET)

Category °	Citation of Document, with indication, where appropriate, of the relevant passages	Relevant to Claim No.
A	APPLIED PHYSICS LETTERS. vol. 55, no. 5, 31 July 1989, NEW YORK US pages 415 - 417 M OKAI ET AL 'Novel method to fabricate corrugation for a lambda/4 shifted dfb lasee using a grating photomask' cited in the application see the whole document ---	1,6
A	GB,A,2 079 536 (COMMISSARIAT A L'ENERGIE ATOMIQUE) 20 January 1982 see figures -----	1

ANNEX TO THE INTERNATIONAL SEARCH REPORT ON INTERNATIONAL PATENT APPLICATION NO. GB 9300750 SA 72484

This annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report.
The members are as contained in the European Patent Office EDP file on
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Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP-A-0175460	26-03-86	DE-A- 3565010	20-10-88
		JP-B- 4049921	12-08-92
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		US-A- 4657780	14-04-87
US-A-4810547	07-03-89	JP-C- 1696784	28-09-92
		JP-B- 3059752	11-09-91
		JP-A- 62225273	03-10-87
		JP-A- 63153746	27-06-88
		JP-A- 63158168	01-07-88
GB-A-2079536	20-01-82	None	